

LESSONS LEARNED FOR COMPOSITE STRUCTURES

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SUMMARY

Lessons learned for composite structures are presented in three technology areas: materials, manufacturing and design. In addition, future challenges for composite structures are presented.

Composite materials have long gestation periods from the developmental stage to fully matured production status. Many examples exist of unsuccessful attempts to accelerate this gestation period. Experience has shown that technology transition of a new material system to fully matured production status is time consuming, involves risk, is expensive and should not be undertaken lightly. The future challenges for composite materials require an intensification of the science based approach to material development, extension of the vendor/customer interaction process to include all engineering disciplines of the end user, reduced material costs because they are a significant factor in overall part cost and improved batch-to-batch pre-preg physical property control.

Historical manufacturing lessons learned are presented using current in-service production structure as examples. Most producibility problems for these structures can be traced to their sequential engineering design. This caused an excessive emphasis on design-to-weight and schedule at the expense of design-to-cost. This resulted in expensive performance originated designs, which required costly tooling and led to non-producible parts. Historically these problems have been allowed to persist throughout the production run. The current/future approach for the production of affordable composite structures mandates concurrent engineering design where equal emphasis is placed on product and process design. Design for simplified assembly is also emphasized, since assembly costs account for a major portion of total airframe costs. The future challenge for composite manufacturing is, therefore, to utilize concurrent engineering in conjunction with automated manufacturing techniques to build affordable composite structures.

Composite design experience has shown that significant weight savings have been achieved, outstanding fatigue and corrosion resistance have been demonstrated, and in-service performance has been very successful. Currently no structural design show stoppers exist for composite structures. A major lesson learned is that the full scale static test is the key test for composites, since it is the primary structural "hot spot" indicator. The major durability issue is supportability of thin skinned structure. Impact damage has been identified as the most significant issue for the damage tolerance control of composite structures. However, delaminations induced during assembly operations have demonstrated a significant nuisance value.

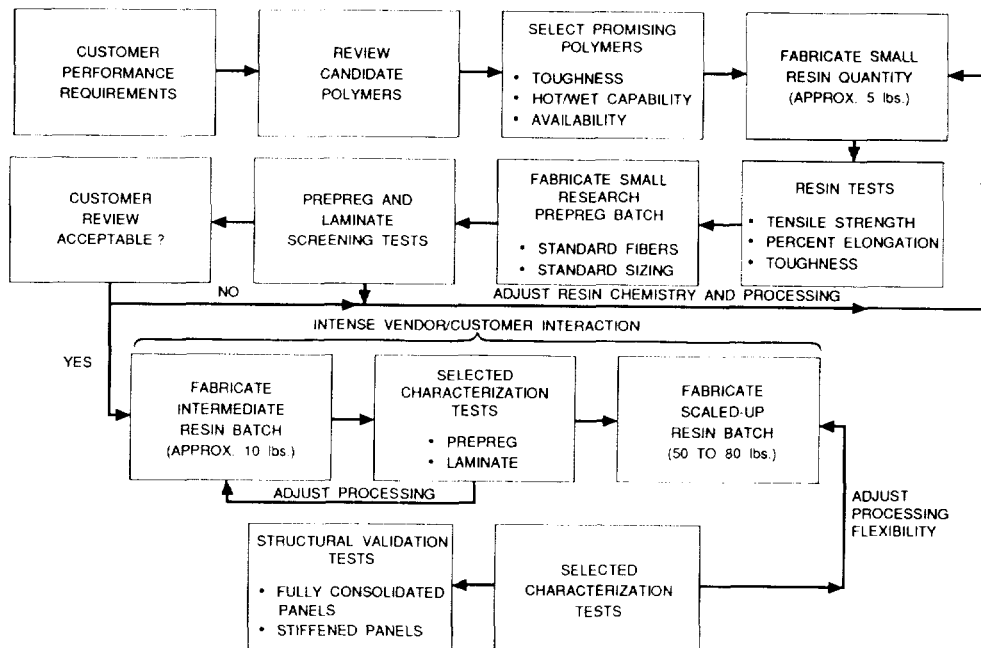
The future challenges for composite structures are threefold. Firstly, composite airframe weight fraction should increase to 60%. At the same time, the cost of composite structures must be reduced by 50% to attain the goal of affordability. To support these challenges it is essential to develop lower cost materials and processes.

Agenda

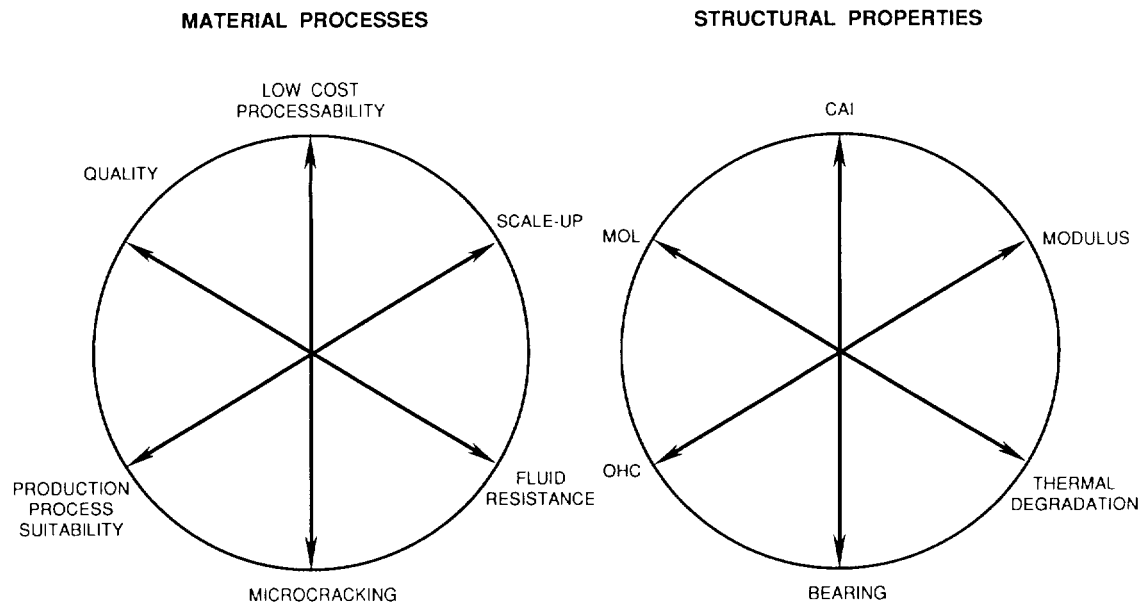
- **MATERIALS**

- Manufacturing
- Design
- Future Challenges

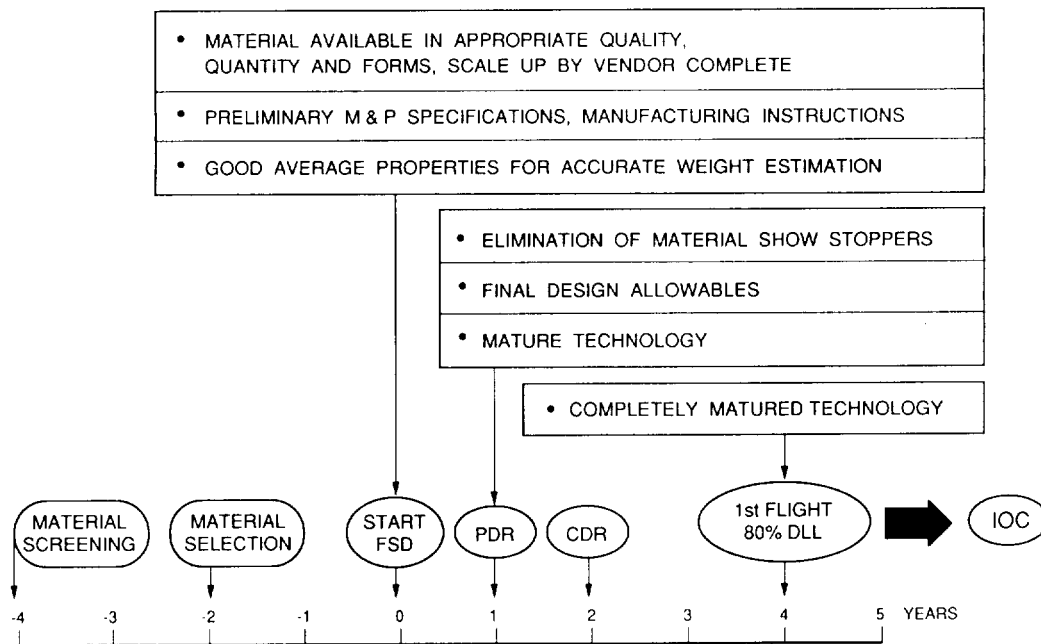
Material Development Process



Material Performance Requirements



Technology Transition Milestones



Technology Transition Problems

Examples

- TOUGH BISMALEIMIDE
- HIGH TEMPERATURE THERMOPLASTIC
- GALVANIC CORROSION INDUCED DEGRADATION OF BISMALEIMIDES AND POLYIMIDES

Lessons Learned

- ALL MATERIALS HAVE LONG GESTATION PERIODS FROM THE DEVELOPMENTAL STAGE TO FULL PRODUCTION STATUS
- ATTEMPTS TO ACCELERATE THE GESTATION PERIOD INVOLVE SIGNIFICANT TECHNOLOGY TRANSITION RISKS
- THERE ARE MANY EXAMPLES OF UNSUCCESSFUL TECHNOLOGY TRANSITION FOR MATERIALS
- TECHNOLOGY TRANSITION OF A NEW MATERIAL TO FULL PRODUCTION STATUS IS TIME CONSUMING, INVOLVES RISK, IS EXPENSIVE, AND SHOULD NOT BE UNDERTAKEN LIGHTLY

Future Challenges

- INTENSIFY SCIENCE BASED APPROACH TO MATERIAL DEVELOPMENT
- EXTEND VENDOR/CONTRACTOR INTERACTION PROCESS TO INCLUDE ALL DISCIPLINES OF END USERS
- REDUCE MATERIAL COSTS BECAUSE THEY ARE A SIGNIFICANT FACTOR IN OVERALL COMPOSITE PART COST
- DRIVE TOWARDS TIGHTER PRE-PREG PHYSICAL PROPERTIES CONTROL ON A BATCH-TO- BATCH BASIS

Agenda

- Materials

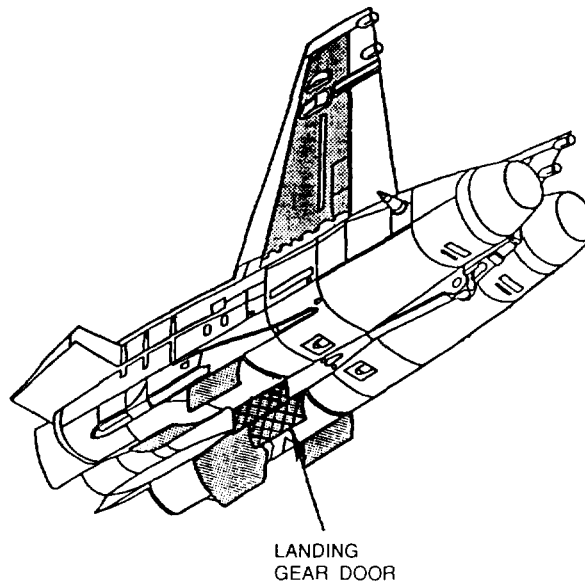
- **MANUFACTURING**

- Design
- Future Challenges

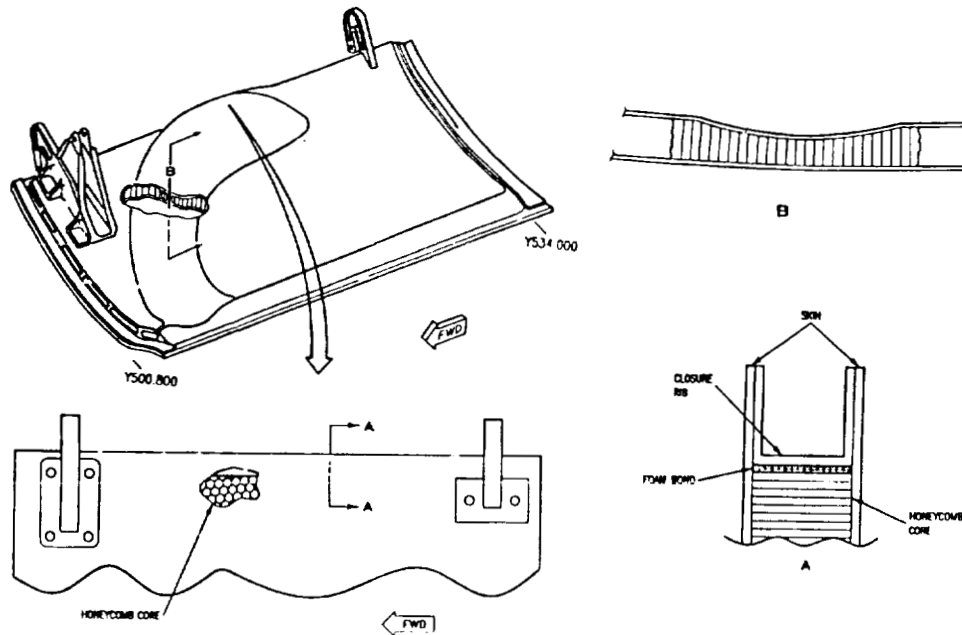
Analysis of Current Approach

- PART PRODUCIBILITY NOT DESIGNED IN
 - Manufacturing Problems With Initial Production
- EXTENSIVE MRB ACTION REQUIRED FOR PART DISPOSITION
 - Substantial Increase in Support Costs
- PART "BUY-OFF" WITH AN EXPENSIVE TEST PROGRAM
 - Inadequate QA and Effects of Defects Database
- RESISTANCE TO REDESIGN FOR PRODUCIBILITY
 - Avoid Design Cost Increase
 - Schedule Driven Production Program
 - Avoid Process Development Costs
- PROBLEM PERSISTS THROUGHOUT PRODUCTION

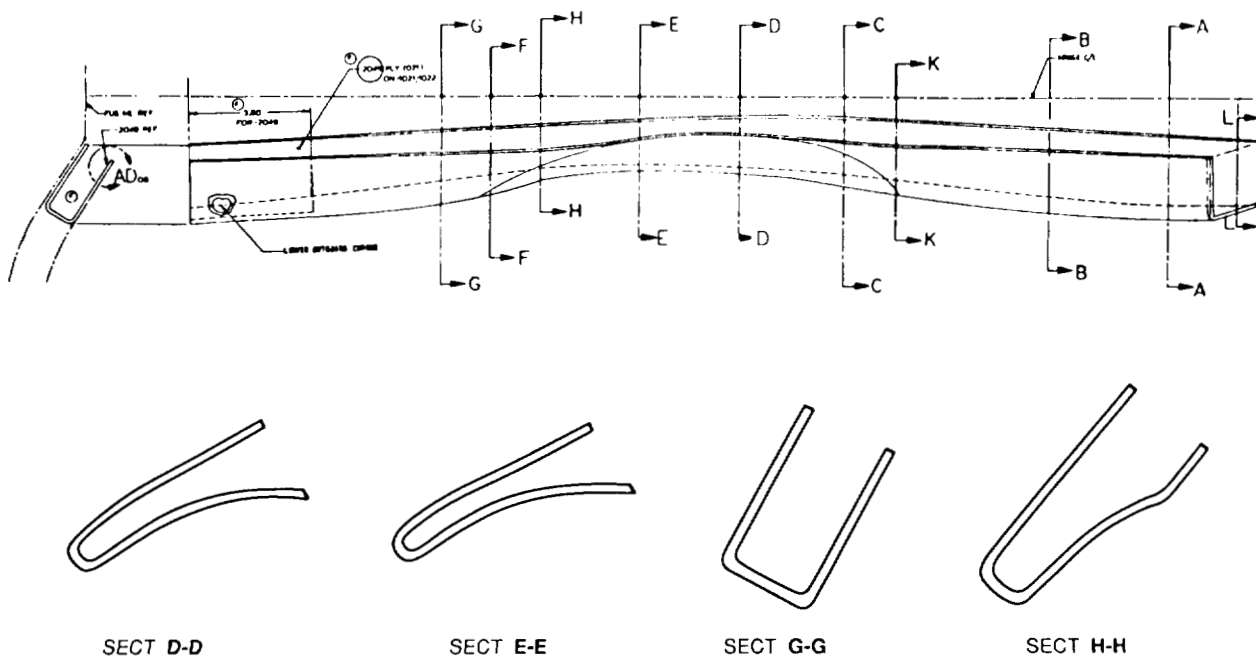
Example F-18 Landing Gear Door



F-18 Landing Gear Door



F-18 Landing Gear Door Stiffener



Door Stiffener Analysis

- NON - PRODUCIBLE SHAPE, I.E., COULD NOT BE PRODUCED REPEATABLY AND COST EFFECTIVELY
- RADIUS DESIGNED FOR FLIGHT LOADS WITHOUT ACCOUNTING FOR TOOL/PART INTERACTION
- PART DIFFICULT TO REMOVE FROM FEMALE TOOL (DICTATED BY ASSEMBLY REQUIREMENTS)
- HIGH REJECT RATE AND MRB ACTIONS DUE TO DELAMINATIONS AND POROSITY IN NARROW REGION

Historical Lessons Learned

- PAY-AS-YOU-GO RATHER THAN SUBSCRIPTION PRICE APPROACH
- DESIGN-TO-WEIGHT AND SCHEDULE WERE PRIMARY DRIVERS
- DESIGN-TO-COST NOT EMPHASIZED DUE TO A LACK OF COST MODELS/METHODOLOGY
- PERFORMANCE ORIENTED DESIGNS REQUIRED EXPENSIVE TOOLING AND SEVERELY AFFECTED PART PRODUCIBILITY
- M&P SPECIFICATIONS DEVELOPED WITHOUT ACCOUNTING FOR 3-D CONFIGURATION
- INSUFFICIENT LEAD TIME FOR TOOL DESIGN AND PROCESS DEVELOPMENT
- QA PLAN NOT INCORPORATED IN PART DESIGN
- NO MECHANISM AND IMPETUS FOR INTERDISCIPLINARY COMMUNICATION AT DESIGN STAGE

Current/Future Approach

- IMPLEMENTATION OF CONCURRENT ENGINEERING
 - Co-Located Multi-Disciplinary Dedicated Teams
 - Personnel Skills Are a Significant Contributor
 - Systematic Checks and Balances
- PROCESS DEVELOPMENT UNDERTAKEN INDEPENDENTLY
 - Separate Design and Manufacturing Development Articles
- DESIGN FOR SIMPLIFIED ASSEMBLY
 - Reduced Part Count
 - Shimless Designs in Certain Areas
- REDUCTION OF POST DRAWING RELEASE CHANGES
- DESIGN-TO-WEIGHT AND DESIGN-TO-COST USUALLY IN CONFLICT
 - Design-To-Weight Dominates
 - D / MI a Key to Balanced Design

Agenda

- Materials
- Manufacturing
- **DESIGN**
- Future Challenges

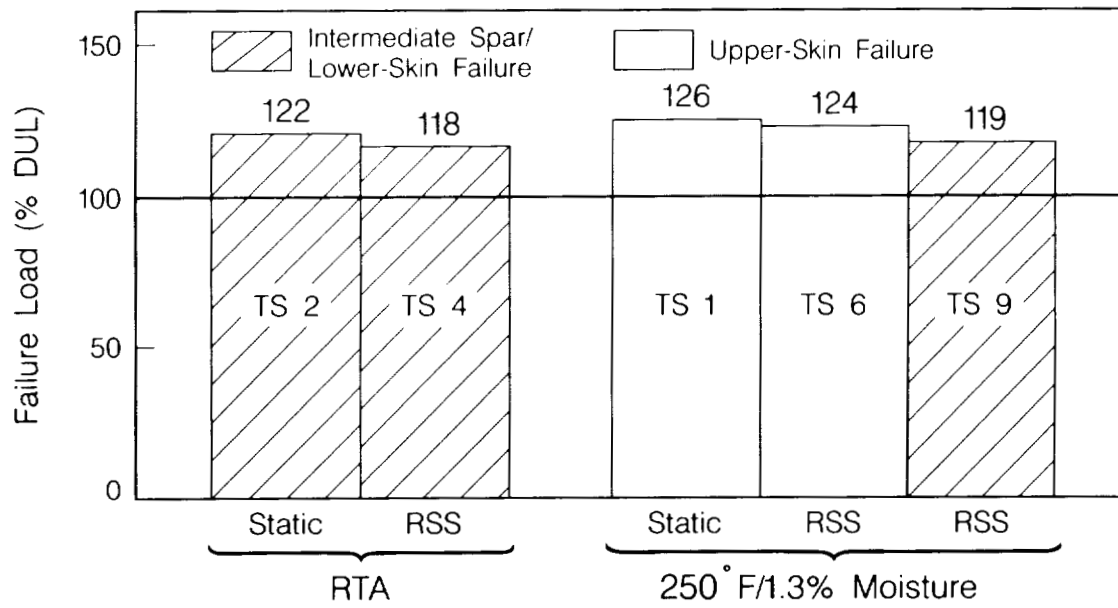
Historical Factors

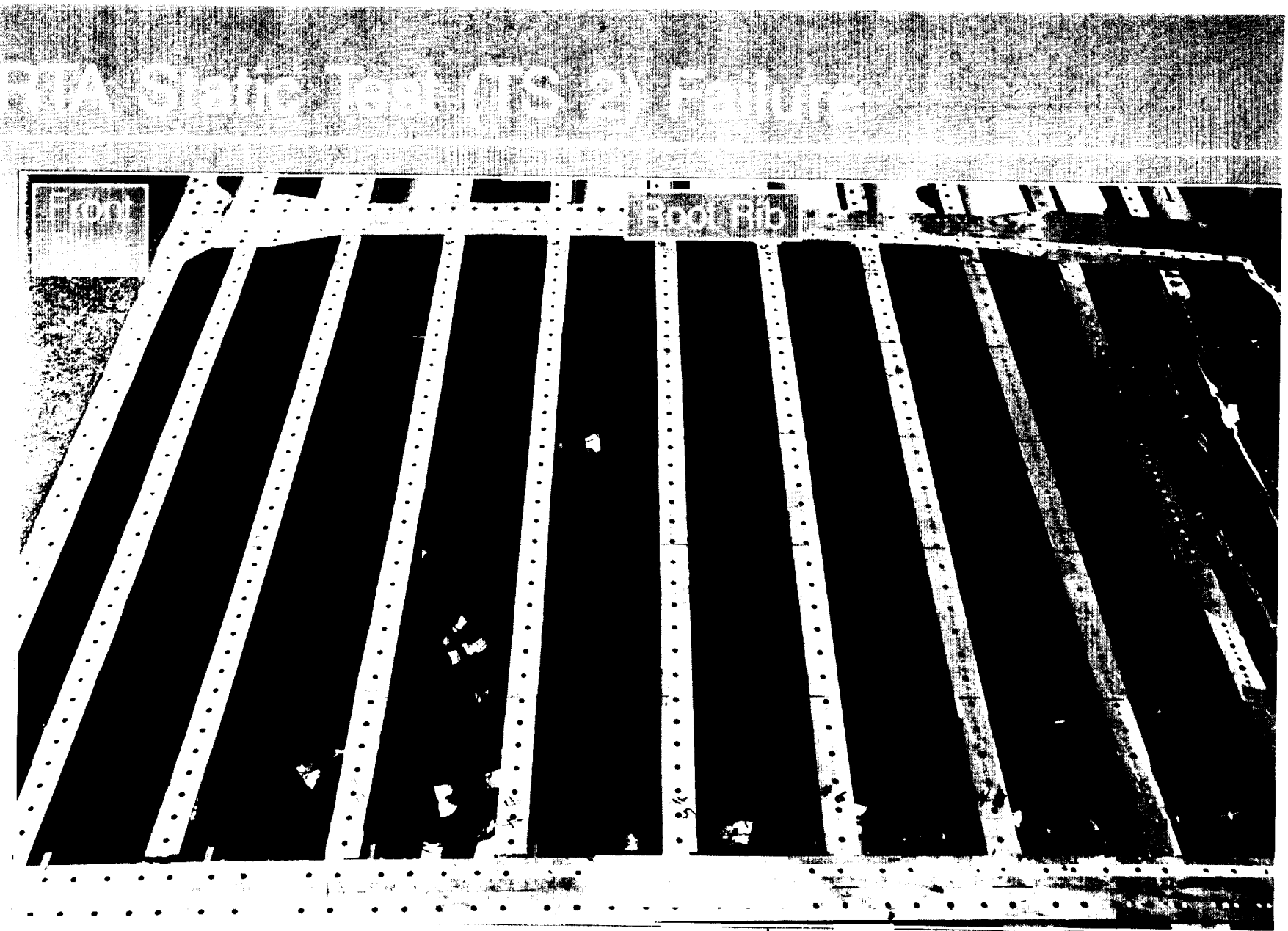
- SIGNIFICANT WEIGHT SAVINGS
- EXCELLENT FATIGUE AND CORROSION RESISTANCE
- MIXED CERTIFICATION EXPERIENCE
- SUCCESSFUL IN-SERVICE EXPERIENCE
(Except Early Vintage Sandwich Structure With Metallic Core)
- NO STRUCTURAL DESIGN SHOW STOPPERS

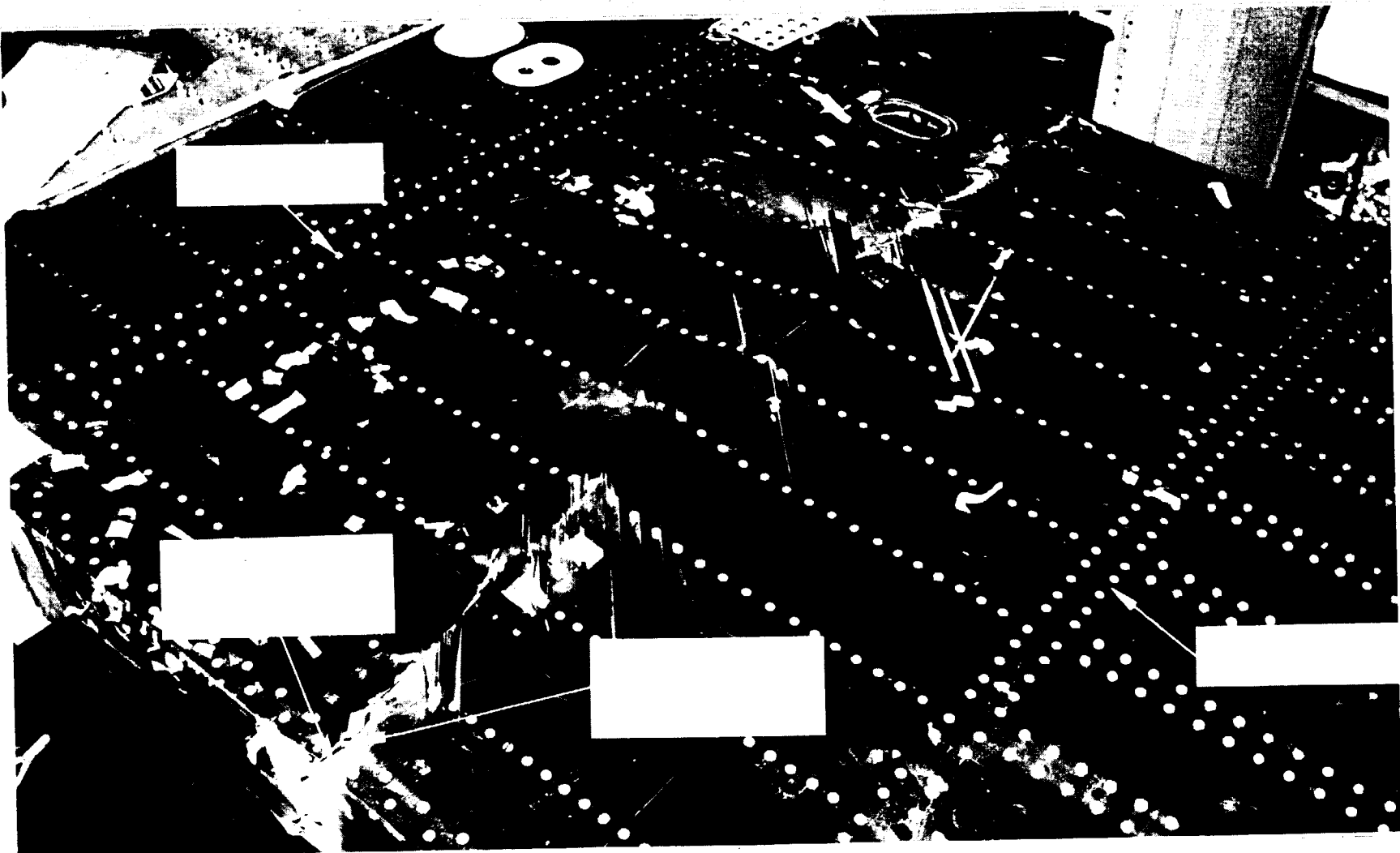
Lessons Learned – Static Strength

- INHERENT PROPERTY DIFFERENCES EXIST BETWEEN COMPOSITES AND METALS
- COMPOSITE STRUCTURES ARE SENSITIVE TO OUT-OF-PLANE LOADS
- MULTIPLICITY OF POTENTIAL FAILURE MODES
- FAILURE MODES OF FULL-SCALE STRUCTURES ARE DIFFICULT TO PREDICT
- STATIC-STRENGTH TEST IDENTIFIES STRUCTURAL "HOT SPOTS"

Wing Component Failure Loads





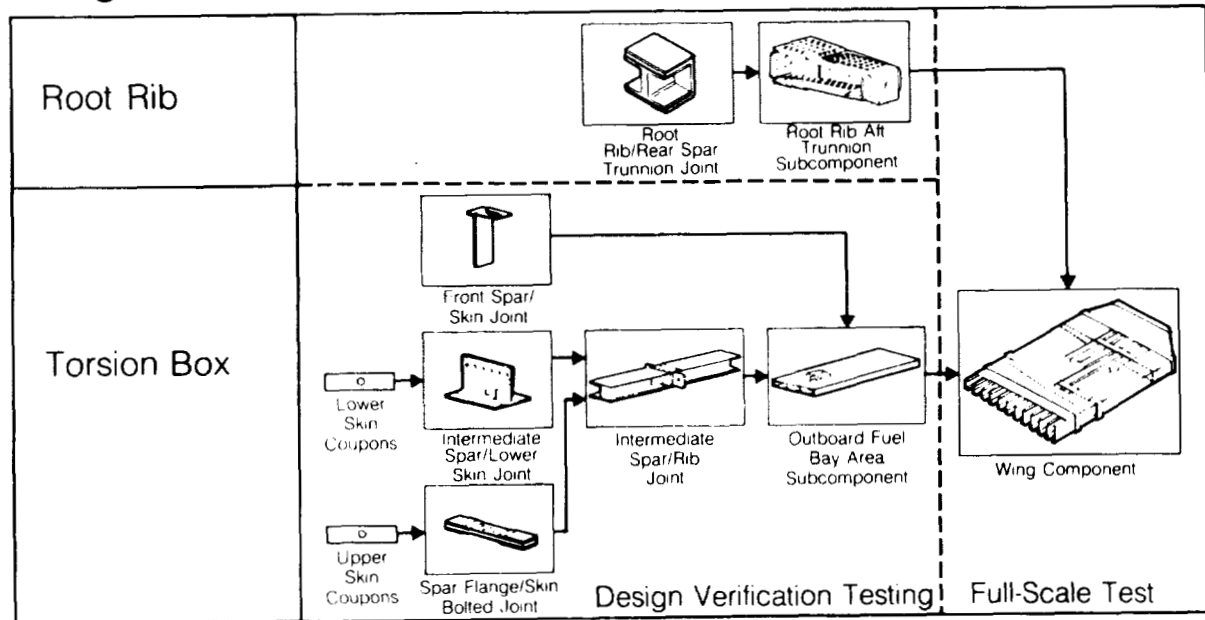


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OF POOR QUALITY

Building-Block Approach

Wing Structure



Lessons Learned – Durability

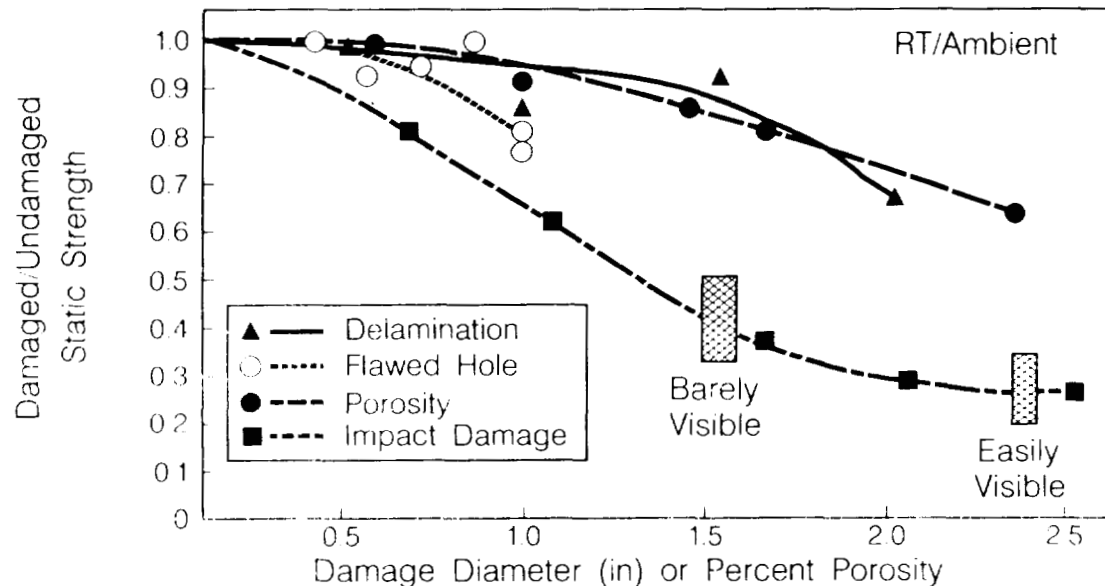
- DURABILITY IS A MEASURE OF ECONOMIC LIFE
- THIN COMPOSITE STRUCTURES ARE SENSITIVE TO LOW-LEVEL (<10 ft-lb) IMPACTS
 - Visible Skin Damage
 - Nonvisible Skin/Core Damage
 - Accelerated Moisture Ingression
 - High Repair Frequency
 - Part Replacement



HIGH MAINTAINABILITY COSTS

Defect/Damage Severity Comparison

Compression



Lessons Learned – Damage Tolerance

- IMPACT DAMAGE IS THE MOST SEVERE DEFECT/DAMAGE TYPE
- IMPACT-DAMAGE AREAS AND STATIC STRENGTH ARE STRONGLY DEPENDENT ON STRUCTURAL CONFIGURATION
- FAILURE MODES OF IMPACT-DAMAGED BUILT-UP STRUCTURE ARE SIGNIFICANTLY INFLUENCED BY STRUCTURAL CONFIGURATION
- SIGNIFICANT IMPACT-DAMAGE TOLERANCE SCALE-UP EFFECTS EXIST FOR BUILT-UP STRUCTURE
- IMPACT-DAMAGED STRUCTURES ARE RELATIVELY INSENSITIVE TO FATIGUE LOADING
- DELAMINATIONS INDUCED DURING ASSEMBLY OPERATIONS HAVE DEMONSTRATED A SIGNIFICANT NUISANCE VALUE

Lessons Learned – Design Criteria

- STATIC STRENGTH, FATIGUE/DURABILITY AND DAMAGE TOLERANCE
- THERE ARE SIGNIFICANT DIFFERENCES BETWEEN USAF, NAVY, ARMY AND FAA REQUIREMENTS
- RATIONALIZATION OF DAMAGE TOLERANCE REQUIREMENTS INTO A SINGLE DOCUMENT IS IN PROGRESS BY J. JAEB (BOEING) THROUGH AIA
- BEWARE OF THESE DIFFERENCES WHEN DESIGNING AN AIRFRAME FOR MORE THAN ONE AGENCY

Agenda

- Materials
- Manufacturing
- Design
- **FUTURE CHALLENGES**

Future Challenges

- REDUCE THE COST OF COMPOSITE AIRFRAME STRUCTURES THROUGH MULTIDISCIPLINARY (MATERIALS, MANUFACTURING, DESIGN) CONCURRENT ENGINEERING
- INCREASE COMPOSITE AIRFRAME WEIGHT FRACTION TO 60%
- DEVELOP LOW COST MATERIALS AND PROCESSES ESSENTIAL IN ORDER TO MEET THESE GOALS